

Evolution of Genetic Concepts for Ohio Soils¹

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ABSTRACT. The earliest genetic concepts of Ohio soils stressed the occurrence of gray eluvial and brown, Fe and Al rich subsoils. Although Conrey recognized clay eluviation-illuviation as an important genetic process as early as the 1930s, clay translocation was not emphasized and documented until the late 1950s and early 1960s. The genetic role of clay eluviation-illuviation was incorporated into Soil Taxonomy, which was adopted as the official USDA soil classification system in 1965, at the Order level establishing the class of Alfisols. In addition, criteria for the identification of argillic horizons were established. Since then studies have shown that the accumulation of clay in the B horizons of Ohio soils is not solely a result of clay illuviation. Subsoil clay accumulation is also attributable to the concentration of parent material clay from carbonate dissolution and *in situ* clay formation. Acreage data generated from the Ohio Cooperative Soil Survey program indicate that 75% of Ohio soils contain B horizons with sufficient illuvial clay to qualify as argillic horizons and 62% of the soils in Ohio classify as Alfisols.

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INTRODUCTION

Soil formation is a complex process involving a multitude of matter, energy, and entropy exchanges between soil and its environment over a lengthy period of time. The complexity of the process was simplified by early pedologists, namely Dokuchaiev, Hilgard, and Jenny (Jenny 1941), who conceptualized soil formation into a model defined by five independent variables: climate, biota, topography, parent material, and time. This model provides a framework for partitioning the factors influencing soil genesis. When considering soil formation from a regional perspective, climate and biota exert the greatest influence on soil formation. In the early soil classification systems of Marbut (1921) and Baldwin et al. (1938), well drained soils with characteristics attributable primarily to the influence of climate and biota were termed zonal soils. Zonal soils can be considered those that have attained a steady-state condition (Smeck et al. 1983) with both the climate and biota, and thus, are the mature soils of a geographic region.

CHARACTERISTICS OF OHIO SOILS

The characteristics of zonal soils in Ohio and surrounding areas were first generalized by Krusekopf (1925), who indicated that the humid, north central states bounded by Wisconsin, New York, Tennessee, and Missouri formed a distinct soil region. According to Krusekopf (1925), the uniform characteristics of soils in this distinct soil region were: a shallow surface-layer with low organic matter content, absence of carbonates to two feet or more, prevailing colors of some shade of brown, and subsoil textures always heavier than those of the surface. He referred to the soils of this region as the "Brown Soils" and attributed their characteristics to the

humid climate. He indicated that the humid climate was responsible for rapid decomposition of organic matter, the leaching of carbonates, and the solution of iron in surface horizons and oxidation in the subsoil giving rise to the brown color. The following year, Baldwin (1926) indicated that Brown Soils of southern Michigan are similar to the Podzols further north as both exhibit light colored A₂ horizons and brown B horizons. Baldwin (1926) also provided data for a Miami profile from Ohio which showed that the B horizon contained twice as much clay (42-43%) as the A horizon (20% clay) and was enriched in Fe and Al. A Miami soil described by Baldwin (1927) became the prototype of soils formed from glacial drift, under deciduous hardwoods, in humid-temperate climates.

In the early U.S. soil classification systems (Marbut 1921, Baldwin et al. 1938), the Brown Soils of Krusekopf were called Gray-Brown Podzolics at the Great Group categorical level. They were considered to be podzol-like because of the light-colored A₂ and the aluminum- and iron-rich subsoil. It is interesting to note that the early emphasis in conceptualizing these soils was placed on the podzol-like A₂ and brown Fe and Al enriched subsoils rather than the clay accumulation in the B horizon.

DEVELOPMENT OF THE ARGILLIC HORIZON CONCEPT

The initial discussion of the genesis of Ohio soils referred to as Brown Soils by Krusekopf (1925) and classified as Gray-Brown Podzolics by Marbut (1921) and Baldwin et al. (1938) was provided by Conrey (1933) of the Ohio Agricultural Experiment Station. He preferred to refer to the soils collectively as Brown Forest soils because their distribution corresponds with the occurrence of broad-leaved deciduous forests. He provided descriptions of several Brown Forest soils (Miami, Russell, Cincinnati, and a Hagerstown-like profile) and two associated poorly drained, intrazonal soils (Crosby and Brookston).

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Conrey (1933) indicated that although the Brown Forest soils formed in calcareous parent materials, at least the upper two feet of the soils were leached of carbonates and in some soils, such as Cincinnati, carbonates were leached to much greater depths. Furthermore, bases and colloidal material were removed from the A_2 horizons, which he suggested be referred to as the "eluvial" horizons. The colloids were deposited in the underlying subsoil, which he termed the "illuvial" zone, yielding heavier textures in the subsoil than overlying horizons.

The following year in Illinois, Bray (1934) addressed the movement of colloidal material in more detail. He indicated that colloidal materials consisting of iron and aluminum silicates of magnesium and potassium start forming early in the weathering process. The process includes the breakdown of coarse colloidal particles to finer colloids lower in K and higher in Mg and Fe. The finer colloids are preferentially eluviated to the illuvial zone. In a later paper, Bray (1935) concluded that the secondary colloidal material formed during weathering in a humid temperate climate is a beidellite-nontronite type of clay mineral, and that horizon development is a result of downward movement of the clay mineral and its accumulation at lower depths. The work of Conrey (1933) and Bray (1934, 1935) was the earliest work to emphasize clay translocation and weathering.

Following a gap in activities in the late forties and early fifties, Thorp et al. (1959) published a landmark paper on the genesis of a Miami pedon located near Richmond, IN. Their study included clay mineralogy and micromorphological investigations. They concluded that most of the "clay bulge" in Miami can be accounted for by movement of clay in suspension with subsequent deposition in the B by drying or flocculation as a result of a chemical gradient. Clay was deposited in the B horizons in the form of oriented skins along pores and on coarse grains and peds. They estimated that non-translocated clay makes up much less than half of the total clay in the B horizons. The weathering of primary minerals was found to contribute only a small portion of the clay in the B horizons. Their mineralogical studies suggested that weathering of illite to vermiculite and montmorillonite is an active process and that much of the translocated clay in the B horizon is montmorillonite. This suggests that montmorillonite is preferentially translocated, which can be attributed to its smaller particle-size.

Statistical summaries of Morley and Blount soils (Wilding et al. 1964) and Miami, Celina, and Crosby soils (Wilding et al. 1965) documented the ubiquitous occurrence of clay-rich B horizons in western Ohio. Characteristics of the clay-rich B horizons reported for Morley and Blount soils (Wilding et al. 1964) included: clay films on both vertical and horizontal ped surfaces, higher fine clay ($<0.2 \mu\text{m}$) contents in B horizons than adjacent horizons with 40 to 45% of the total clay ($<2 \mu\text{m}$) in B horizons consisting of fine clay, and B₂/A clay ratios of greater than 2.

In 1965, the National Cooperative Soil Survey adopted a new classification system (Soil Survey Staff 1960) which recognized the illuvial horizon in which silicate clays accumulate as a diagnostic feature for classes at the

highest categorical level, the Order. The horizon of illuvial clay accumulation was designated an argillic horizon. The argillic horizon is considered to be the most diagnostic feature of soils in which clay eluviation-illuviation is a major genetic process. Criteria for the argillic horizon included: evidence of illuvial clay in the form of clay skins on both vertical and horizontal ped surfaces, a 20% increase in clay relative to overlying eluvial horizons, and more fine clay than the C horizon. To allow time for revision after implementation, the soil classification system was not published until 1975 (Soil Survey Staff 1975). Based on acreage figures for mapping units used in Ohio, soils covering approximately 75% of the land area in Ohio possess argillic horizons. Eighty-three percent of the soils with argillic horizons classify as Alfisols.

PROCESSES INVOLVED IN ARGILLIC HORIZON FORMATION

Shortly after implementation of the new classification system, comprehensive studies of the formation of argillic horizons in Alfisols of western Ohio were initiated (Smeck et al. 1968, Smith and Wilding 1972). Three soil series, Celina, Morley, and Nappanee, were studied in north-south transects along the western border of Ohio and extending into Michigan. Celina occurs over loam till, between the Camden and Bloomer moraines, which has a mean calcium carbonate equivalent (CCE) of 40% (Wilding et al. 1965), Morley occurs over clay loam or silty clay loam till, between the Bloomer moraine and Lake Maumee shoreline, which has a mean CCE of 24% (Wilding et al. 1964), and Nappanee occurs over clay loam, silty clay loam, clay, or silty clay till deposits in the lake plain of northwestern Ohio (Smith and Wilding 1972). All three soils have argillic horizons as shown by prominent increases in clay content between the eluvial and illuvial horizons (Fig. 1) and the occurrence of clay skins (argillans) on ped surfaces in the B horizon (Fig. 2). However, because of a lithologic discontinuity between the A and B horizons in each soil caused by a loess mantle, clay ratios and comparisons between the B and C horizons are more appropriate criteria for recognition of illuviated clay. For the pedons involved in these studies, the average Bt/C total clay ratios are 1.9, 1.4, and 1.3, and fine clay/coarse clay ratios for the horizon with maximum clay content are 1.0, 0.6, and 0.7 for Celina, Morley, and Nappanee pedons, respectively. The latter are 1.5 to 3 times greater than the average fine clay/coarse clay ratios for the C horizons of all three soils which range from 0.3 to 0.4. Both particle-size distributions and micromorphological observations suggest that Celina soils have the most strongly expressed argillic horizons. Celina soils also contain the highest CCE in the C horizons and the carbonate contents of the tills generally decrease from south to north. Thus the influence of carbonate contents in the tills on clay contents in the argillic horizons caused by carbonate leaching was evaluated. Comparisons of carbonate-free clay distributions with clay distributions in the field, i.e., with calcareous C horizons, indicate that all three soils show clay bulges on both calcareous and carbonate-free expressions (Fig. 1);

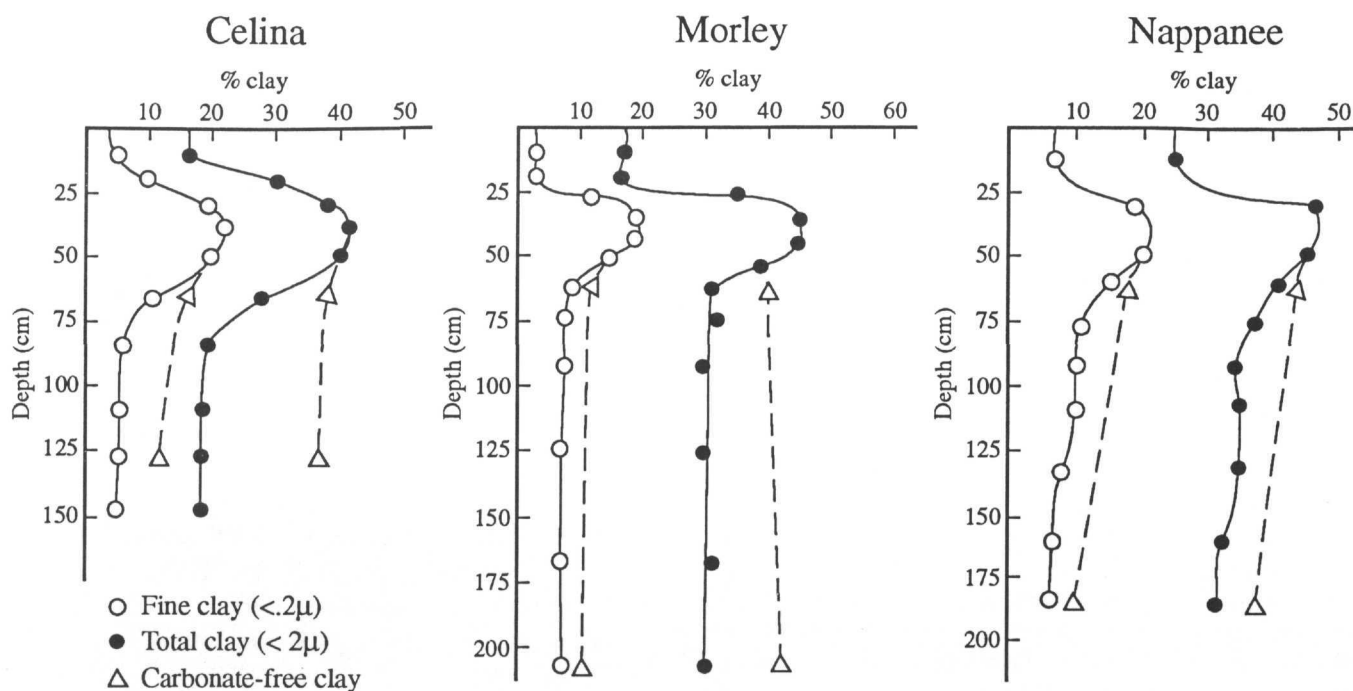


FIGURE 1. Fine and total clay distributions (provided on both a carbonate and carbonate-free basis below the depth of carbonate leaching) for a Celina, Morley, and Nappanee pedon (Smeck et al. 1968, Smith and Wilding 1972).

however, the clay bulges are noticeably suppressed on a carbonate-free basis. This clearly indicates that much of the textural profile development in the soils of western Ohio can be attributed to clay concentration as a result of carbonate dissolution.

Nevertheless not all of the clay in the B horizon can be accounted for by clay concentration. To accurately assess the magnitude of clay accumulation from clay illuviation, carbonate-free particle size distributions must be expressed on a volume basis so that volume changes accompanying carbonate dissolution can be taken into consideration. In order to estimate volume changes, an internal index was used. The index must be a weathering resistant component in a non-mobile fraction which will concentrate as the

carbonates dissolve. In the Ohio studies (Smeck et al. 1968, Smith and Wilding 1972), Zr content in the sand and silt fractions were employed. The results of such reconstructions for Celina, Morley, and Nappanee soils (Table I) show coarse, fine, and total clay gains or losses in B horizons using an underlying C horizon as a reference. All three soils show coarse clay losses and fine clay gains with gains decreasing on moving north in the state from Celina to Nappanee soils. The fine clay gains can be attributed to either the accumulation of illuvial clay or to the *in situ* formation of clay. Estimations of the volume of oriented clay from thin sections (such as shown in Fig. 2) for Morley and Celina shows close agreement with the fine clay gains (Smeck et al. 1968). This agreement suggests that the fine clay gains are a result of clay illuviation. Further interpretation of these data suggests that clay illuviation has been more active in Celina than the soils further north. This should be expected because the soils become progressively younger on moving north. In summary, it was concluded that the clayey B horizons in soils of western Ohio were attributable to clay translocation and clay concentration resulting from carbonate dissolution with the former becoming progressively more important on moving south.

Similar studies of argillic horizons in soils derived from low carbonate (3-15%) tills of northeastern Ohio also showed both fine and total clay gains in the argillic horizons of Remsen, Mahoning, Bennington, Wadsworth, and Platea pedons (Ritchie et al. 1974). Whereas clay translocation and subsequent illuviation could account for essentially all of the clay gains in Mahoning and Wadsworth argillic horizons, a substantial amount of the clay gains in the Remsen, Bennington, and Platea pedons could not be accounted for by illuviation and thus were attributed to

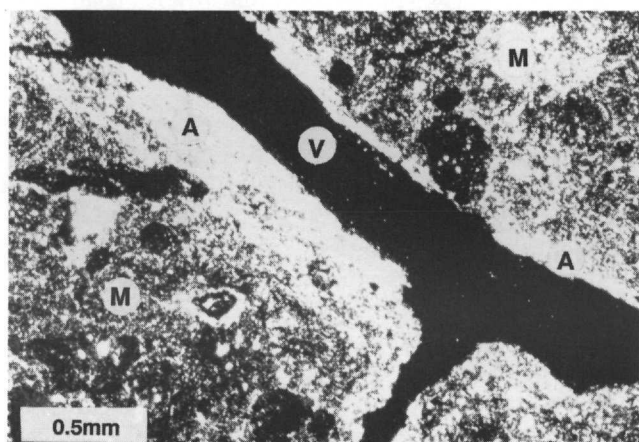


FIGURE 2. Photomicrograph of a thin section of a Bt horizon of a Celina pedon from western Ohio. Well expressed argillans (A) lining ped surfaces are evident. The features labeled include: argillans (A), soil matrix (M), and voids between peds (V).

TABLE 1

Calculated gains or losses of total and fine clay in the horizon with maximum clay content in a Celina, a Morley, and three Nappanee pedons from western Ohio.

Soil	Fine Clay ($<0.2\ \mu\text{m}$)	Coarse Clay ($0.2\text{--}2\ \mu\text{m}$)	Total Clay ($<2\ \mu\text{m}$)
	g/100 cc		
Celina ¹	+18	-3	+16
Morley ¹	+14	-8	+6
Nappanee (PT-28) ²	+10	-8	+2
Nappanee (HN-97) ²	+13	-1	+12
Nappanee (FT-18) ²	+8	-10	-2

Gains and losses of clay were calculated on a volume basis using the Zr content in the 0.002 to 2 mm fraction as an index.

¹From Smeck et al. (1968).

²From Smith and Wilding (1972).

in situ formation. Micromorphological observations revealed that shale lithics in the C horizons are numerous, have sharp boundaries, and show little evidence of exfoliation or disintegration; however, shale lithorelics in the argillic horizons are not nearly as numerous, and show pronounced fraying and exfoliation along edges (Ritchie et al. 1974). Estimates of shale contents from thin sections indicated that the C horizons contained at least 3 times more shale than the argillic horizons. Rostad et al. (1976) reported data which indicate that physical disintegration of the non-carbonate sand (1-2 mm) and gravel (2-4 mm) fractions will add clay-size particles. In addition, they provided data which show that pebbles of sedimentary origin decrease between C and argillic horizons but pebbles of resistant crystalline rocks are concentrated in argillic horizons. These data indicate that the physical disintegration of coarse particles, particularly sedimentary shales, contribute to clay accumulation in B horizons. This mechanism is undoubtedly most important in B horizons of soils derived from the shale-rich tills of eastern Ohio.

As an extension of the studies of argillic horizons formed in glacial tills, a reconstruction evaluation of argillic horizons in Fox and Eldean soils formed over calcareous glacial outwash was conducted to determine if clayey argillic horizons could be derived from the coarse textured, gravelly deposits comprising the stream terraces, kames, and eskers in the state (Rostad et al. 1976). Four soils with well expressed argillic horizons containing 26 to 50% clay over coarse-textured C horizons containing 3 to 9% clay and 63 to 87% gravel were investigated. Carbonates in the gravelly outwash exhibit a distinctly bimodal particle-size distribution comparable to the tills examined in earlier studies (Fig. 3). Maximum carbonate contents occur in the coarse silt and coarse sand or gravel fractions with the latter containing greater than 80% CCE. Conversely, the clay fraction contains very little carbonate ($<5\%$), thus carbonate dissolution should yield a substantial increase in clay content. Reconstruction analysis documented that all four soils showed gains of both coarse and fine clay in

the argillic horizons with maximum fine clay gains ranging from 9 to 31% (Rostad et al. 1976). It was concluded that 32 to 37% of the clay in the argillic horizon was attributable to carbonate residues and the concentration of parent material clay from carbonate dissolution, 43% was attributable to translocation, and the remainder to the disintegration of shale, siltstone-sandstone, and crystalline lithics. Although prior to the study of Rostad et al. (1976), it was generally accepted that a lithologic discontinuity occurs between the solum and calcareous, gravelly outwash, the conclusion from this study was that fine textured argillic horizons can be derived from glacial outwash and that the textural discontinuity between the solum and outwash may be entirely genetic.

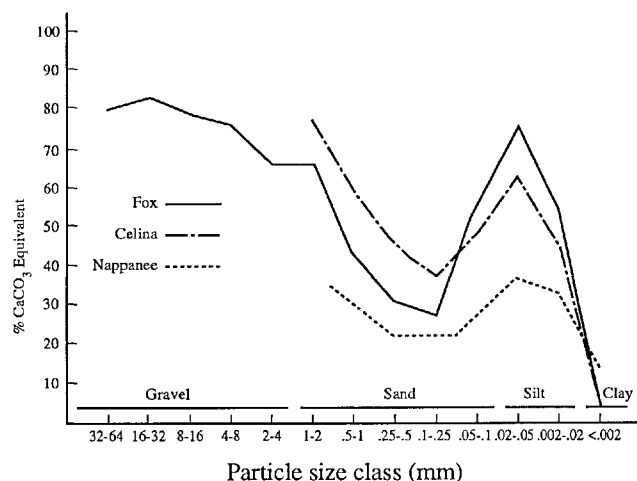


FIGURE 3. Carbonate contents (% CaCO_3 equivalent) in size fractions of C horizons from three representative glacial soils from western Ohio (Fox, Celina, and Nappanee) (Smeck and Wilding 1980).

By the mid-seventies, the mechanisms involved in the formation of argillic horizons in mature, well to somewhat poorly drained soils in Ohio had been clearly established. Although many poorly to very poorly drained soils had been classified as having argillic horizons, this had not been documented. Furthermore, because the development of soil acidity in eluvial horizons and sufficient water percolation is necessary for clay translocation (Rust 1983), there were reservations as to whether argillic horizons would form in poorly drained environments. Thus a study was initiated to determine if there was sufficient clay translocation in poorly drained soils for the B horizons to qualify as argillic horizons (Smeck et al. 1981). Five poorly drained soils were examined: Hoytville, Brookston, Toledo, Montgomery, and Pewamo. Data for particle size distribution showed that although all pedons except Brookston showed clay gains in B horizons, only two pedons, Hoytville and Toledo, showed sufficient clay gains for the B horizons to qualify as argillic horizons. Reconstruction evaluations of the soils indicated that the clay gains in all pedons except Hoytville could be attributed to clay concentration from carbonate leaching, shale disintegration, or *in situ* formation of fine clay from the coarse clay and silt fractions, with the latter

process being dominant. Only the Hoytville pedon contained horizons showing clay gains that exceeded losses of the other size fractions. Although such clay gains support clay illuviation, micromorphological examinations of thin sections could not detect sufficient illuvial clay skins in any of the B horizons to support the occurrence of argillic horizons. The study suggested that it is unlikely that poorly drained soils possess argillic horizons and that the classification of these soils should be reconsidered.

Recent studies have refined our understanding and appreciation of argillic horizons. Ransom et al. (1987) concluded that argillic horizon degradation is one of the most important genetic processes in seasonally wet soils on the Illinoian till plain of southwestern Ohio. The degradation of clay minerals comprising illuvial cutans was attributed to alternating oxidation-reduction conditions which promote a process referred to as ferrollysis. Shipitalo et al. (1988) concluded that more pedogenic clay accumulation occurs over clayey underlying materials than over coarser materials. This was attributed to impeded water movement which promotes clay illuviation. In the most recent study, Amba et al. (1990) found evidence for multiple clay bulges in some soils of the loess-capped unglaciated region of Ohio. The multiple clay bulges provide strong evidence that the Alfisols of southeastern Ohio have been subjected to multiple episodes of clay illuviation which have been interrupted by erosional and/or depositional events.

SUMMARY

The genetic concept of Ohio soils has evolved from that of Brown Soils and Gray-Brown Podzolic soils with emphasis on the occurrence of a gray eluvial horizon and a brown, Fe and Al rich B horizon, to that of Alfisols with emphasis on the accumulation of illuvial clay in the B horizon. Research in Ohio, however, has shown that the accumulation of clay in B horizons does not result solely from clay illuviation. The clay accumulation is also attributable to the concentration of parent material clay resulting from carbonate dissolution and *in situ* clay formation, particularly the disintegration of shale. Nevertheless, it has been conclusively documented that mature, somewhat poorly to well drained soils in Ohio contain B horizons with sufficient illuvial clay to qualify as argillic horizons, and that the soils are properly classified as Alfisols with genetic emphasis on clay eluviation-illuviation.

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